AGRICULTURAL MEMORANDUM NO.528

RESTRICTED CIRCULATION

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On the response, to exposure to cold, of young beef cattle

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1. Introduction

The purpose of this note is to bring together the further information that will be needed for an examination of the economic consequences of the thermal environment on the growth of young beef cattle. We are concerned essentially with the effects on production (live weight gain) of exposure to cold environments, defined here as environments below the Critical Temperature of the animals.

Ag. Mem. 526 dealt primarily with the role of environmental variables in determining the Critical Temperature; the factor (H), the heat production in a thermoneutral environment, was taken as given in situations treated numerically. We now need to show how (H) may be derived generally, given information on the size of the animal and its feed ration.

We need next to establish the physical consequences (in terms of weight loss) of environments below the Critical Temperature.

Finally, we need to enquire as to the probable frequency and degree of exposure to environments below the Critical Temperature in the Eastern Region.

2. Heat production

We require to examine how (H), the heat production in a thermoneutral environment, may be derived quite generally, given information on the age or weight of the animal, the ration amount, mix and quality (i.e. concentration) and the daily weight gain.

The procedure involved is not simple, but may be inferred, in principle, from Blaxter (1962) and in more detail from Cuthbertson (1965).

A table, taken from Cuthbertson and reproduced below, summarises the energy requirements of growing and fattening cattle. It incorporates both an energy balance approach and experimental evidence on the efficiency of utilisation of metabolised energy for maintenance and for growth as a function of the ration mix.

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Table 1

Estimates of the energy required by growing and fattening cattle

(Mcal metabolisable energy/day)

Live weight W(kg)	Ration concentration (Mcal/kg dry) matter	Rate of gain (kg/day)						
		0	0.25	0.50	0.75	1.00	1.25	1.50
200	1.8	8.6	10.5	12.9	15.8	-	-	-
	2.2	8.3	9.8	11.5	13.6	16.3	-	-
	2.6	8.0	9.2	10.6	12.3	14.3	16.7	19.7
	3.0	7.7	8.7	9.9	11.3	13.0	14.9	17.3
	3.4	7.5	8.4	9.4	10.6	12.0	13.8	15.7
300	1.8	10.5	12.8	15.3	18.8	-	-	-
	2.2	10.2	11.9	13.9	16.3	19.5	-	-
	2.6	9.8	11.2	12.8	14.7	17.2	20.3	-
	3.0	9.4	10.6	12.1	13.6	15.6	18.0	21.0
	3.4	9.1	10.2	11.4	12.8	14.6	16.5	19.1
400	1.8	12.4	15.1	18.0	22.1	-	-	-
	2.2	12.0	14.1	16.4	19.3	22.9	-	-
	2.6	11.5	13.2	15.0	17.4	20.9	23.9	-
	3.0	11.1	12.6	14.1	16.0	18.3	21.3	25.0
	3.4	10.8	12.1	13.4	15.0	17.0	19.5	22.7

Table 1 is concerned with energy intake (metabolisable energy) and energy retention (live weight gain). Our interest is rather in the difference between energy intake and the energy retention i.e. the (heat) energy output of the animal. It is suggested that a further table, corresponding to Table 1, but showing the heat production (H) under the same various combinations of circumstances will meet the generality of situations in which (H) is required to be known.

We need initially to establish the fasting metabolism of the animals. Preferred mean values (from Cuthbertson 1965) are set down, together with an estimate of the weight appropriate to a given age in Table 2.

Table 2

Preferred mean values for the fasting heat production of cattle

Age of animal (months)	Live weight (kg)	Fasting metabolism (kcal/kg $W^{0.75}$) per day
1	60	140
3	125	135
6	170	125
12	330	110
18	400	100
24	450	95

(kg W) represents the liveweight expressed in kg.

If we assume that at a live weight of:

200 kg the daily fasting metabolism is 120 kcal/kg $W^{0.73}$
300 kg the daily fasting metabolism is 110 kcal/kg $W^{0.73}$
400 kg The daily fasting metabolism is 100 kcal/kg $W^{0.73}$

and note that $(200)^{0.73} = 47.8$
$(300)^{0.73} = 64.6$
$(400)^{0.73} = 79.4$

then the fasting heat production of the animals is as follows:

Liveweight	Fasting heat production
200 kg	5736 kcal/day
300 kg	7106
400 kg	7940

It is convenient at this point to also establish the surface area of the animals with which we deal. The general relationship that for the fasting animal, heat production is equal to 1450 kcal/m^2/day, sets the surface area as follows:

Liveweight	Surface area
200 kg	4.0 m^2
300 kg	4.9
400 kg	5.4

Again drawing on Cuthbertson (1965) we produce relations between the energy retained by the animal and the calorific value of the live weight gain in cattle.

Table 3

Equations for estimating the calorific value of live weight gains in cattle of different weight

Weight of animal (kg)	Equation C = Calorific value of gains in kcal/kg S = Energy retained in kcal/day
200	C = 2150 + 0.25S
300	C = 2500 + 0.27S
400	C = 2900 + 0.28S

To obtain (S), the energy retained, for a nominated daily live weight gain (G) we note that at 200 kg live weight

$$G = \frac{S}{C} = \frac{S}{2150 + .25S}$$

For this relationship we find (at 200 kg live weight) the following:

G	S
0 kg	0 kcal
0.25	564
0.50	1310
0.75	1985
1.00	2870
1.25	3900
1.50	5150

Referring to the information set down in Table 1, we are able now to carry out calculations of the following kind, noting that the total heat production consists of the fasting metabolism plus the heat increment due to feed.

At Live weight 200 kg and Ration concentration 1.8

Live weight gain (kg)	Metabolised Energy (kcal/day)	Retained Energy (kcal/day)	Heat production (kcal/day)
0	8600	0	8600
0.25	10500	564	9936
0.50	12900	1310	11590
0.75	15800	1985	13815

Similar calculations enable us to set down the information contained in Table 4.

Table 4

Estimates of the heat production of growing and fattening cattle (kcal/day)

Live weight (kg)	Ration concentration (Mcal/kg dry matter)	Rate of gain (kg/day)						
		0	0.25	0.50	0.75	1.00	1.25	1.50
200	1.8	8600	9936	11590	13815	–	–	–
	2.2	8300	9236	10190	11615	13430	–	–
	2.6	8000	8636	9290	10315	11430	12800	14550
	3.0	7700	8136	8590	9315	10430	11000	12150
	3.4	7500	7836	8090	8615	9430	9900	10550
300	1.8	10500	12130	13855	16380	–	–	–
	2.2	10200	11230	12455	13880	16070	–	–
	2.6	9800	10530	11355	12280	13770	15600	–
	3.0	9400	9930	10655	11180	12170	13300	14750
	3.4	9100	9530	9955	10380	11170	11800	12850
400	1.8	12400	14320	16310	19350	–	–	–
	2.2	12000	13320	14710	16650	18900	–	–
	2.6	11500	12420	13310	14750	16200	18300	–
	3.0	11100	11820	12410	13250	14300	15700	17500
	3.4	10800	11320	11710	12250	13000	13900	15200

The information of Table 4, together with that of Ag Mem 526 enables estimates of the Critical Temperature to be made.

3. Relation between exposure to temperatures below the Critical Temperature and production losses

We need to establish the additional energy (heat) losses imposed by a departure from a thermoneutral environment whose lower limit is identified by T_c, the Critical Temperature.

Following the notation of Ag Mem 526, we have

$$H = H_s + H_e + H_w$$

and $$H = KA(T_B - T) + H_e + H_w$$

where H represents the heat production in a thermoneutral environment

H_s represents the sensible heat loss
H_e represents the evaporative heat loss
H_w represents the body heat used in raising the temperature of the ration to body temperature
K represents the cooling constant
A represents the surface area of the animal
T_B represents the body temperature
T represents the environmental temperature.

At the Critical Temperature

Heat Production = $KA\ (T_B - T_C) + H_E + H_W$

At 1 deg C below the Critical Temperature

Heat production = $KA\ (T_B - T_C - 1) + H_E + H_W$

By subtraction, the additional heat production required for a 1 deg C departure from the Critical Temperature is seen as

$$KA \text{ kcal/day}$$

Alternatively we may write:

$$\frac{dH}{dT} = -KA$$

As we have noted already (Ag Mem 526), K, the cooling constant is simply the slope of the line relating the rate of sensible heat loss (H_S) to the environmental temperature (T). This information offers an alternative method to the evaluation of K from the summation of the conductances of body tissue, coat, and coat/air interface.

For an animal with a normal coat, under the 'still air' conditions of the calorimeter, observation suggests typical values of K to be of the order 40-50 Kcal/m^2/day/deg C.

For the field animal, exposed to an air movement of 2.5 m/s, the values of K computed from the conductances (as in Ag Mem 526 under various multipliers for wind effects) are found to be

Index of conductance multiplier	0.7	0.6	0.5
Value of K (Kcal/m^2/day/deg C)	64	61	58

Rounded values for K, in cold environments are taken to be:

50 Kcal/m^2/day/deg C in "still air"
60 Kcal/m^2/day/deg C at 2.5 m/S.

The production of heat, to meet the additional environmental demand due to departures from the thermoneutral zone, must come from body reserves.

The relation between feed energy retained, the calorific value of live weight gains and live weight gain is not reversible. By this we mean that the calorific values of unit live weight gains are not the same as the calorific values of unit live weight losses. This is because under cold stress the breakdown (oxidation) of fat takes place preferentially, and only a small loss of body protein occurs. The proportion of the energy required, in the cold stress situation, that is derived from protein, probably varies with fat reserves and so with the age of the animal. For the purposes of our calculations we assume that the partition of the additional heat energy required to meet

departures from the thermoneutral zone will be similar to that which occurs under fasting. For animals of the weight range considered in this note we take the percentages of the heat required will be derived from protein, 14%; from fat 84%.

We have now to assign heats of combustion to body fat and body protein.

For body fat we adopt the value of 9.3 Kcal/g. For body protein the value we adopt is necessarily an approximation, since the 'correction' for incomplete combustion necessarily varies with its chemical composition; however, we take the value for protein of 3.5 Kcal/g.

For the 200 kg. animal, in still air, we establish a supplementary environmental demand to be met by body reserves of:

$$50 \text{ Kcal/m}^2\text{/day/deg C below } T_c$$

For a surface area of 4.0 m^2, this becomes 200 Kcal/day degrees (C) below Tc.
Of this 200 Kcal,
28 Kcal will be derived from protein = 28/3.5 = 8g body weight loss
168 Kcal will be derived from fat = 168/9.3 =18g body weight loss.

For the 200 kg, in 'still air', the weight loss is 26g/day degrees C below T_c.

A corresponding calculation, when the air movement is 2.5 m/s and K has a value of 60 Kcal/m^2/day/deg C below T_c indicates a weight loss of 31g/day degree C below T_c.

4. Day degrees below a given base in the UK
Country wide comparisons for the average year

An air temperature of 42°F i.e. 5.6°C has long been identified as a threshold for crop growth. Because of this wider general interest (and since this temperature is close to the Critical Temperature (5.3°C) of store cattle that was inferred in Ag Mem 473, and close to the lower limit of the possible values suggested for fattening cattle (5.4°C) at a daily live weight gain of 0.5 kg in wind speeds of 2.5 m/s (Ag Mem 526)) we have examined the occurrence of day degrees below 5.6°C for the purpose of broad, country wide comparisons in the average winter.

Figure 1 shows for the average season (from long-period average monthly mean data) the day degrees below 5.6°C at sites throughout the UK. Individual values used in drawing the isopleths were reduced to mean county height by the correction of 1 day degree C per metre. The season considered was the months of November through to March, both months inclusive.

We may comment, on the basis of Figure 1, that the Eastern Region of ADAS would appear to be as cold as any other part of the country except perhaps for the high ground of Northern England and Scotland.

Data on which Figure 1 is based are given in an appendix.

The implication of Figure 1 (and the appendix) at Cambridge for example, is that average seasonal weight loss due to cold stress could be of the order:

$$346 \times 31\text{g} = 10.8 \text{ kg.}$$

For the 200 kg store animal, fed to appetite on poor to medium quality hay only, this could be a positive loss.

For the animal fattening at the rate of 0.5 kg/day, it would imply a delay of the order 3 weeks in arriving at s nominated body weight.

This is in the average season. It is of obvious interest to examine the losses and the frequency of occurrence of winters more severe than the normal.

6. The distribution of Day Degrees below a given base over a typical sample of years

6.1 A procedure

This distribution must be discussed in relation to specific sites and we choose one in the Eastern Region.

In order to establish a general procedure to arrive at the required distribution from long period average monthly mean temperature data, (and so avoid the necessity examining detailed, daily data for many years) we turn to the data of Rothamsted. These have already been worked up by others in day degrees F and for simplicity we retain this as our unit in this section. The simple conversion to day degrees C is made by dividing day degree F values by 1.8.

At Rothamsted, in December the average accumulated temperature below 42°F is 157 day degrees F. What is the distribution of accumulated temperature below 42°F in a typical sample of years?

We make the common assumption that monthly mean temperature is normally distributed. If σ is the standard deviation of the normal distribution,
x is the ordinate distance from the distribution mean, T_m,
then, from the probability integral, the values of x/σ at the mid points of each 10% range are given by

$$x/\sigma = \pm .125; \pm .385; \pm .670; \pm 1.04; \pm 1.645$$

Shellard (1959) maps values of σ for each month. Knowing the long period average monthly mean temperature, T_m, we may obtain the values of monthly mean temperatures in a sample distribution of 10 years from the relationships.

$$T_m \pm .125\sigma$$
$$T_m \pm .385\sigma$$
$$T_m \pm .670\sigma$$

etc.

For each of the 10 monthly mean temperatures so obtained, we make the assumption that the day degrees appropriate to each month may be obtained by the procedure of Thom (1954). This is the step that needs to be justified here.

The procedure outlined above, when applied to the data of Rothamsted for the months of December, January and February leads to the following table.

Table 5 Accumulated temperature below 42°F (day degrees F)

Month/Year	1	2	3	4	5	6	7	8	9	10
December	279	259	199	183	167	156	137	121	107	71
January	322	277	248	223	206	185	168	149	126	96
February	226	177	154	140	123	108	96	83	65	45
Winter quarter	827	713	601	546	496	449	401	353	298	211

An independent assessment of the accumulated temperature below 42°, using daily data (and the procedure indicated in Met Form 3300) is available in an unpublished memorandum (1965) of the Agricultural Section of the Meteorological Office. Over an 18 year period, this gives the following distribution for the winter quarter.

Table 6 Observed values of accumulated temperature

Year	Day degrees (F) below 42°F	Year	Day degrees (F) below 42°F
1	880	10	445
2	770	11	435
3	725	12	405
4	670	13	395
5	575	14	390
6	520	15	385
7	495	16	365
8	490	17	355
9	470	18	315

It may be shown that for practical purposes, the distributions of tables 5 and 6 are similar, both in regard of distribution means (t - test) and distribution variance (F - test).

5.2 Some results for the Eastern Region

Noting an observed value of the order 5.3°C for the Critical Temperature of 200 kg steers, in a group in the farm situation, fed to appetite on poor to medium quality hay, we examine the accumulation of degree days for bases around this value of 5.3°C for Mildenhall, in the Eastern Region, over a typical sample of years.

Table 7 Station Mildenhall

Accumulation of day degrees centigrade below various bases for a typical sample of years

Base/Year	1	2	3	4	5	6	7	8	9	10
- 0.7°C	8	12	22	30	41	46	53	70	87	129
1.3	18	42	55	66	83	95	112	131	170	235
3.3	62	91	124	140	162	190	219	250	290	400
5.3	131	172	219	253	285	322	345	400	448	555
7.3	240	300	360	400	492	449	541	600	745	800
9.3	393	494	568	655	668	720	772	832	910	1070
11.3	595	710	790	865	920	985	1030	1100	1190	1415
13.3	850	1010	1080	1140	1220	1280	1340	1400	1500	1650

These data are for the winter and early spring period i.e. November through to March, both months inclusive.

SUMMARY

Memorandum 526 and the present one, together, enable estimates of the Critical Temperature to be made. The procedure takes account of both environmental variables and the heat production by the animals.

A relation between depature from the Critical Temperature and weight loss under cold stress is established. The unit of cold stress is the day degree centigrade below the Critcal Temperature.

The occurrence of day degrees below 5.6°C on a country wide basis, for the average season, is examined, for the purposes of comparison.

A procedure is established to obtain the variation in day degrees below any base for a typical sample of years.

It is intended to bring all this information together in a further Memorandum No.529 to examine the economic consequences of cold stress under various managements strategies.

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STATION	Height above Mean Sea Level METRES	Mean County Height METRES	Day Degrees c at Station Level BELOW 5.6°C	Average Day Degrees c at Mean county Height °C
Cape Wrath	112	146	276	310
Strathy	37	146	396	505
Achrashellach	67	149	393	475
Benbecula	6	7[illegible]	248	318
Duntulm	90	149	307	366
Onich	15	174	344	503
Ft Augustus	21	174	412	565
Nairn	6	143	374	511
Lossiemouth	6	131	397	522
Gordon Castle	32	131	380	479
Balmoral	283	247	651	615
Craibstone	91	171	449	529
Dyce	58	171	450	563
Rattray Ha	26	171	382	527
Stonehaven	4	125	354	475
Dundee	45	128	405	488
Buddon Ness	5	128	412	535
Arbroath	29	128	376	475
Perth	23	152	427	556
Kirkaldy	42	125	373	456
St Andrews	4	125	366	487
Turnhouse	35	177	378	520
Davidson's Mains	61	177	392	508
Blackford Hill	134	177	365	408
Liberton	61	177	364	480
N Berwich	46	107	347	408
Dunbar	23	107	332	416
Marchmont	152	152	441	441
Colonsay	27	146	265	384
Oban	70	146	314	390
Glenbrantar	24	146	396	518
Bermore YBG	12	146	338	472
Rothesay	43	70	309	336
Helensburgh	89	88	400	399
Stirling	46	101	373	428
Falkirk	30	101	388	459
Greenock	61	128	310	377
Paisley	32	128	319	415
Renfrew (Springburn)	8	128	355	475
Glasgow	107	180	428	501
Turnberry	8	152	283	427
Largs	6	152	279	425
Auch	45	152	337	444
Kilmarnock	34	152	350	468
Dun	43	104	380	441
Glenlea	55	137	403	485
Bellughan	259	140	552	433
Berwick-on-Tweed	23	140	349	466
Chopwellwood	136	156	396	416
Ushaw College	181	156	413	388
Ampleforth	95	112	390	407
Scarborough	36	112	328	404

STATION	METRES	METRES	BELOW 5.6°C	°C
Hull	2	46	302	346
Waddington	68	40	349	321
Cleethorpes	7	40	311	344
Skegness	5	40	328	363
Dovercourt	3	50	295	342
Huddersfield	99	117	369	387
" (Oatas)	235	117	408	290
Bradford	134	117	392	375
Ilkley	96	117	392	413
Wakefield	37	117	342	422
Ballykelly	2	104	214	316
Moneydig	34	104	263	333
Aldergrowe	69	121	285	337
Hillsboro'	116	82	304	270
C. Archdale	66	113	257	304
Belper	62	145	369	452
(Prof Note 125)				
Wick	36	110	345	419
Fortrose	21	146	338	403
Stornoway	3	79	248	354
Tiree	9	114	157	262
Aberdeen	24	171	338	485
Renfrew	9		358	
Leuchars	10	76	355	421
Colmonell	55		287	
Douglas	87	91	197	201
Ke	78	120	324	372
Cockle Park	99	140	388	429
Tynemouth	33	140	256	363
Durham	102	155	388	441
Stoneyhust	118		338	
York	18	113	370	465
Southport	11	88	287	364
Holyhead	8		135	
Bidston	61	67	279	285
Sheffield	131	117	331	317
Nottingham	59	56	331	325
Welshpool	78	131	347	400
Birmingham	130	101	348	318
Cambridge	12	23	345	358
Gorleston	2	35	278	311
Sandown	4	56	196	248
Larkhill	132	121	357	346
Boscombe Down	126	121	382	377
Squires Gate	10	88	308	386
Morcombe	7	88	317	398
Ringway	76	88	338	350
Macclesfield	152	67	385	300
Rhyll	9	107	238	336
Hawarden Br.	5	107	272	374
Valley	10	50	166	206
Colwyn Bay	36	166	184	314
Llandudno	4	122	168	2866
Aberporth	133	174	211	252
Aberystwyth	4	174	209	379

STATION	METRES	METRES	BELOW 5.6°C	°C
Aberystwyth PBS	138	174	247	283
Haverfondwest	40	94	188	242
Lland. Wells	235	235	355	355
Swansea (Mon)	8	127	196	315
Newport	23	125	268	370
Weston S. Mare	9	91	223	305
Weymouth	5	90	192	277
Tavistock	139	128	219	208
Ilfracombe	8	128	154	274
Torquay	8	128	166	286
Exmouth	59	128	211	280
Sidmouth	8	128	195	315
Penzance	19	111	75	167
Lizard	73	111	84	122
Newquay	54	111	120	177
Fowey	40	111	108	179
Bude	15	111	137	233
Woburn	89	85	424	420
L. Sutton	46	79	351	384
E. Malling	41	73	386	418
Wye	50	73	359	382
L. Ashton	49	91	301	343
Cannington	29	91	250	312
N. Abbott	115	129	220	234
Ellbridge	61	111	215	265
Gulval	6	111	108	213
Aber	18	121	163	266
Parkend	99	111	293	305
(L.H)				
Terrington	4	40	338	374
Cromer	54	35	295	276
Lowestoft	25	46	259	280
Luton	159	85	379	305
Cardington	29	85	359	425
St Albans	83	104	383	404
Stansted	101	50	380	329
Shoeburyness	2	50	302	350
Clacton	16	50	327	361
Wittering	65	107	355	397
Raunds	59	107	384	432
St Anns Head	43	94	125	176
Cardiff	62	126	257	321
Ross-on-Wye	68	123	296	351
Oxford	64	111	320	367
Rothamsted	128	103	411	386
Felixstowe	3	50	293	340
Kew	5	41	301	337
Marlboro'	129	122	376	369
Wisley	46	85	311	350
Cullompton	62	128	307	241
Shaftsbury	198	90	400	292
Penton	111	122	363	374
Southampton	20	79	202	261
Dungeness	6	73	272	339
Plymouth	27	111	120	204
Portland Bill	10	90	149	229
Ventnor	18	56	155	193
Scilly	50	-	37	37
Armagh	63	99	264	300
Manchester	38	88	184	234

STATION	METRES	METRES	BELOW 5.6°C	°C
Spurn Head	9	46	265	302
Newton Rigg	171	127	473	429
Houghall	49	155	453	559
Sealand	5	67	311	373
Cromwell	62	40	389	367
S. Bovington (Salop)	48	56	408	416
Newport	64	131	420	497
Worcester	29	76	373	420
Sprowsten	28	35	357	364
Thetford	15	35	508	528
Pontefract	78	46	362	330
Buxton	307	145	512	350
Mansfield	110	56	377	323
Finningley	10	40	352	387
Edgebaston	163	101	339	277
Coventry	103	101	368	366
Shewsbury	56	131	338	413
Shawbury	71	131	360	420
Lyonshall	156	123	364	331
Filton	58	111	309	362
Cheltenham	65	111	331	377
Heathrow	25	41	305	321
Waddon	67	85	307	325
Addington	145	85	347	287
Bromley	64	73	292	301
Tunbridge Wells	106	73	364	331
Dover	6	73	258	325
Margate	15	73	244	302
Bognor Regis	7	64	267	324
Littlehampton	5	64	272	331
Worthing	8	64	266	322
Eastbourne	7	64	257	314
Abingdon	64	111	319	366
Shinfield	61	98	329	366
Reading	43	98	303	348
Rugby	118	101	392	375
Hastings	45	73	255	283
Bournmouth	39	79	263	303
Southsea	2	79	227	304
S. Farnboro'	68	79	314	325
St Cath's Point	16	56	213	253

Average accumulated degree days below 5·6°C at mean county height below 1000 ft.